ATTACHMENT 3

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DRAFT NEW RECOMMENDATION ITU-R SF.[4-9S/ESV-C]

Guidance for determination of interference from earth stations on vessels to stations in the fixed service when the ESV is within the "minimum distance"

(Questions ITU-R 226/9 and ITU-R 254/4)

The ITU Radiocommunication Assembly,

considering

a) that WRC-2000 adopted Resolution 82 calling for ITU-R to urgently complete its studies related to ESVs, in particular not to have the potential to cause unacceptable interference to stations of other services of any administration;

b) that vessels may be equipped to operate FSS earth stations (ESVs) which transmit in the FSS networks in the 5 925-6 425 MHz band (Earth-to-space) under No. 4.4 of the Radio Regulations (RR);

c) that vessels may be equipped to operate as ESVs in the 14-14.5 GHz band under No. 4.4 of the RR or as secondary service in the MSS;

d) that some of the bands in considering b) and c) are shared on a co-primary basis with the Fixed Service;

e) that if ESVs were to be permitted to operate in sea-lanes and channels near to shore it would be necessary to define composite areas for these operations

f) that Recommendation ITU-R SF.[Doc. 4/85-9/108] provides a way to define such an area;

g) that stations in the fixed service within such an area must be examined to determine whether they will experience more than a permissible amount of interference;

h) that many fixed service digital systems operate under automatic transmit power control (ATPC);

j) that interference events of more than a few seconds can result in significant long-term outages in digital fixed service systems;

k) that Recommendations ITU-R SF.1006 and/or ITU-R SM.1448 provide methods that could be used for the determination of interference potential between stations in the fixed-satellite service and stations in the fixed service when the ESVs are stationary (see NOTE 1);

l) that the methodology for determining the level of interference from ESVs to FS stations is a matter for agreement between the administrations concerned;

m) that guidance to administrations on the detailed determination of these levels for performing a preliminary analysis may nonetheless be of value to some in the detailed assessment of interference;

n) that Recommendations ITU-R F.696 and ITU-R F.[Doc. 9/BL/21] define permissible interference criteria for stations in the fixed service;

o) that different methods and interference criteria are needed to determine the interference potential from earth stations on board vessels when these are not fixed;

recommends

1 that the guidance described in Annex 1 may be used as a framework for the overall assessment of interference from earth stations on board vessels operating within the "minimum distance" to stations in the fixed service;

2 that the guidance in Annex 2 may be used as the basis for the calculation of interference from ESVs (see NOTE 2 and NOTE 3);

3 that results of the application of the method in Annex 2 can be used to determine whether portions of the frequency bands in considering b) may be considered for use by ESVs when operating within the "minimum distance"* (see NOTE 3).

NOTE 1 – The methods given in this Recommendation make use of FS interference protection criteria. As an example, Recommendation ITU-R SF.1006 provides such criteria but the short-term criteria may only be compliant with Recommendation ITU-T G.821. On the other hand, Recommendation ITU-R SF.[ESV-A] provides FS short term protection criteria for up-to-date links designed to meet the requirements of Recommendations ITU-T G.826 and G.828.

NOTE 2 – When identifying frequencies for ESVs, mitigation techniques may need to be considered. For example, in the case where the FS frequency arrangements are based on Recommendation ITU-R F.383-6, the use of the 6 GHz FS central band (close to 6.175 GHz) by the ESV transmitters can significantly reduce the potential interference to the FS receivers since, when considering interference to any FS channel, there would be benefit from receiver filtering.

NOTE 3 – The method in Annex 2 may be supplemented by the use of the method in Annex 3.

* For the definition of minimum distance see Recommendation ITU-R SF.[ESV-A].

ANNEX 1

Guidance for identifying and using points on the operating contour for the determination of interference from emissions from an ESV in motion to a station in the fixed service (Critical Contour Point Method)**

The following method may be used as a framework for the overall assessment of interference from earth stations on board vessels operating within the minimum distance to stations in the fixed service.

1 Introduction

The method for assessing interference potential between a station in the fixed-satellite service (FSS) and a station in the fixed service (FS) is provided in Recommendation ITU-R SF.1006, which assumes that the FSS and the FS stations have a fixed spatial relationship. ESVs moving into a port or harbour to a dock or anchorage have a variable relationship with FS stations while in-motion.

Draft new Recommendation ITU-R SF.[Doc. 4/85-9/108] describes a method for using the operating contour of ESV-equipped vessels to determine an area which can be used in identifying the FS stations that could experience unacceptable interference from an ESV as it is travelling along this contour. Under existing procedures, the potential for such interference would need to be evaluated as if it were stationary at each possible point along a vessel's route whenever it is within this area.

This Annex provides a methodology called the Critical Contour Point Method which simplifies the determination of interference potential to FS stations to consideration of a small set of points on the operating contour. Each of these points is designated as a Critical contour Point (CCP). Some of these points are specific to the operating contour, whereas others are specific to the particular FS station.

2 Considerations in determining the CCP

2.1 Stationary operation

For stationary operation of an ESV, the potential for interference can be assessed using Recommendation ITU-R SF.1006 or ITU-R SM.1448 or by any procedures agreed between the administrations involved as they would be applied to any new FSS station.

2.2 In-motion operation

Each FS station within an area (for example, as described in draft new Recommendation ITU-R SF.[Doc. 4/85-9/108]) must be examined to determine whether it will experience more than a permissible amount of interference. This would normally require assessment of the interference potential with respect to each FS station at each point along the route of an ESV-equipped vessel in-motion within the operating contour. However, the Critical Contour point (CCP) methodology offers an approach to reducing such computational requirements by identifying a small number of points for each FS receiver within a certain area.

** The operating contour is defined in DNR SF.[Doc. 4/85-9/108].

2.2.1 Identification of the CCP for each potentially-affected FS receiver

For any interference exposure of a particular FS receiver from an ESV terminal on a moving ship, there are three position-related variables in the calculation:

1) propagation loss exceeded for all but a percentage of time. This loss depends on the length of the interference path, the Radio-Climatic Zones and may include the effects of any blockage that may exist on the interference path;

2) FS receiver antenna gain; and

3) ESV antenna horizon gain.

For every point within the operating contour as defined by the deep-draft channel (see Figure 1), each of these three factors can be readily determined.

For the purpose of evaluating the potential interference the operating contour is approximated by a set of straight-line segments. The identification of the critical contour points depends on the position and alignment of the FS path with respect to the operating contour, and several cases need to be distinguished. In those cases where the azimuth of the main-beam axis of the FS antenna does not intersect with any portion of the operating area of the ESV, the critical contour points are the points along the operating contour where the contour changes direction or reaches the off-shore limit beyond which coordination is not required. In those cases where the azimuth of the main-beam axis of the FS antenna intersects the operating contour it is necessary to augment and/or modify the number of CCPs. In any event, the same critical contour points should be used to consider both the long-term and the short-term interference to any FS station under consideration. Interference from in-motion ESV operations to any FS receiver within the area where the potential interference from the ESV needs to be evaluated is assessed by consideration of the operation at each of the CCPs for each receiver using propagation loss models such as those given in Recommendation ITU-R P.452. The goal of this assessment is the identification of frequencies that can be used for in-motion ESV operations without causing unacceptable levels of interference to FS stations.

For the identification of the critical contour points with respect to a specific FS receiver, the following three cases need to be distinguished.

Case 1: In this case the main beam axis of the FS receiving antenna does not intersect any portion of the operating contour. The only critical contour points required for this case are the points where the operating contour of the ESV changes direction.

Case 2: In this case, the main beam of the FS antenna (within 10 dB of the maximum antenna gain) lies entirely within one segment of the operating contour. The points on the operating contour where the antenna gain is 10 dB below the maximum, determine two additional critical contour points. The segment of the operating contour between these two CCPs contains the Natural Intersection Point (NIP), the point where the main beam axis of the FS antenna intersects the operating contour. The NIP is always taken as a CCP.

Case 3: In this case, the NIP is close enough to one of the points where the operating contour changes direction that the main beam of the FS antenna extends over more than one segment of the operating contour. This case is most likely to arise when the NIP is close to one of the points where the operating contour of the ESV changes direction. The intersection of the operating contour with the antenna 10 dB points determine two additional critical contour points as in Case 2; however, in this case the original point within the main beam does not need to be considered as a critical contour point.

A further possibility: If there is a point on the operating contour of an ESV from which the maximum horizon gain of the ESV antenna is directed toward a FS receiver, that point on the contour may be identified as an additional CCP for that FS receiver regardless of which of the three Cases applies.

2.2.2 Consideration of long–term interference

The long-term interference is determined by an aggregation of the interference power from each segment of the operating contour from the pier to the end of the operating contour beyond which coordination is not necessary. That is, from in a summation of the contributions resulting from operation between each of the successive CCPs with respect to an FS receiving station. The procedure as elaborated in Annex 2 uses the principle of FDP from Recommendation ITU-R F.1108. The only difference is that the propagation loss needed for the calculation is the propagation loss from each CCP that is exceeded for all but 20 percent of the time. The contribution to the FDP from each segment may be calculated in closed form based on the average interference power received due to ESV operation within the segment, including the effect of the duration of time spent in the segment in multiple passes of ESVs. For a segment that does not contain an NIP this average is computed by assuming that the sum of the gain (in dB) of the FS and the ESV antennas varies linearly over the segment. The average over a segment containing an NIP is determined based on a gaussian shaped main-beam of the FS antenna as in Recommendation ITU-R F.1245.

The criterion that is applied to this interference is the power level taken for long-term interference in Recommendation ITU-R SF.1006 or ITU-R F.758.

2.2.3 Consideration of short–term interference

The acceptability of short term interference may be determined by considering whether the interference power due to operations near any critical contour point exceeds the value specified by the short-term criterion for more than an acceptable percentage of time, p_{ST}. The short-term interference criteria used in Recommendation ITU-R SF.[4-9S/ESV-A] for the 6 and 14 GHz bands may be used for this purpose.

The determination of the short-term interference power due to ESV operation near a CCP depends on the propagation loss on the path from that CCP. In particular, it depends on the propagation loss exceeded for all but a small percentage of time, a percentage that is inversely proportional to the percentage of time (p_{ESVi}) associated with the ESV operation near that critical contour point. This approach, described in detail in Annex 2, is similar to that used in Recommendation ITU-R SF.1485, or in § 2.2.2 of Annex 1 to Recommendation ITU-R SM.1448. The percentage of time associated with ESV operation near a critical contour point depends on which situation applies of those that can occur under the three cases described above in § 2.2.1.

In cases where the main-beam axis of the FS has a natural intersection point on the operating contour of the ESV, the percentage of time (p_{ESVi}) associated with the ESV operation near that NIP is directly related to the time it takes for an ESV to move along the operating contour between the two 10-dB points of the FS antenna.

Except for the CCPs that are adjacent to an NIP, which are treated as end points of the operating contour, the percentage of time p_{ESVi} depends on the time it takes the ESV to move from the mid-point of the preceding segment of the operating contour to the midpoint of the following segment of the contour. Where the CCP is an end-point of the operating contour, one of these segments does not exist and its contribution is set to zero.

There is also a possibility that more complex situations can occur, but these can be addressed using an approach similar to the one suggested here.

3 Application of CCP methodology in identifying available spectrum

The spectrum available for ESV terminals on ships under way in or near ports can be determined using the CCP methodology to evaluate whether use of a particular frequency will result in more than a permissible amount of interference between the ESV and stations in the fixed service.

After the critical contour points have been determined for a FS receiving station, Annex 2 may be used to determine whether both the long-term and short-term interference levels are acceptable. Those frequency ranges where ESV operation can be shown not to cause unacceptable interference to any FS receiver can then be assigned for use by ESVs that visit that particular port.

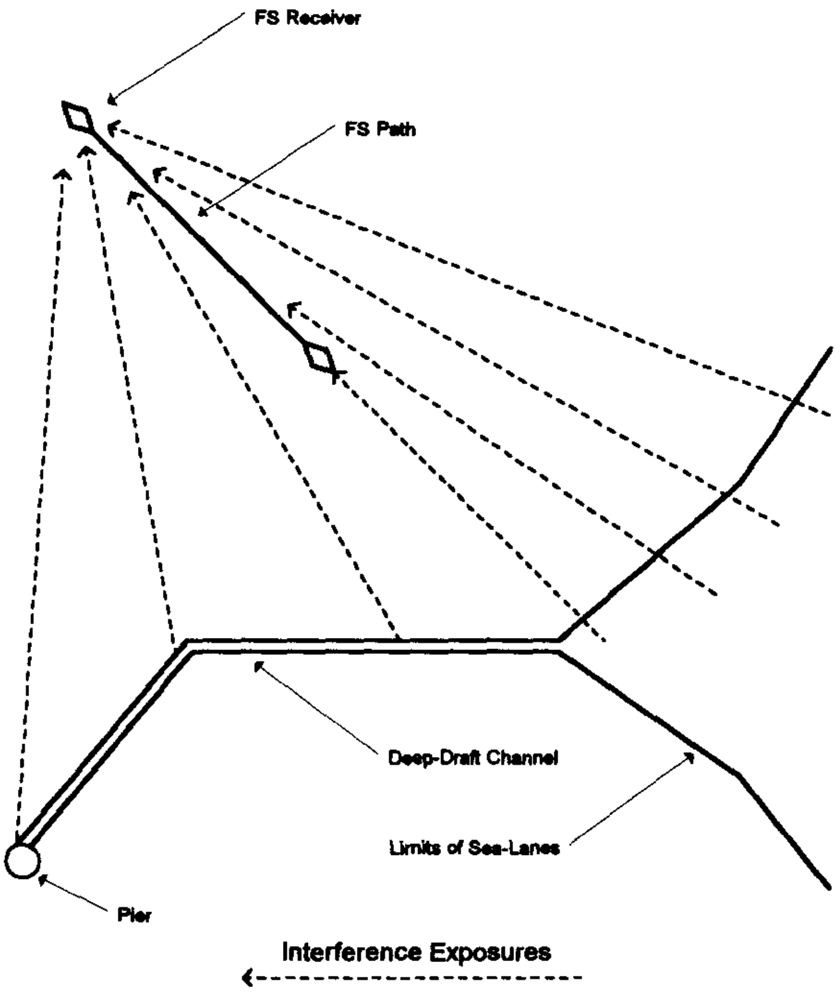

FIGURE 1

Basic interference geometry

ANNEX 2

The calculation of interference from earth stations on board vessels

1 Introduction

Resolution 82 (WRC-2000) is concerned with provisions for Earth Stations on Vessels (ESVs) operating in the frequency bands 3 700-4 200 MHz and 5 925-64 25 MHz. Three new Recommendations were developed in WP 4-9S, two of these only require consideration of short-term interference criteria. These are Recommendation ITU-R SF.[4-9S/ESV-A] which addresses the off-shore distance beyond which interference into the fixed service need not be considered and Recommendation ITU-R SF.[4-9S/ESV-B], which addresses the determination of the area within which the interference potential of ESVs needs to be considered in instances where the possibility of operations within the off-shore distance are contemplated. The third, this Recommendation, addresses the determination of the potential of ESVs to interfere when operating within the offshore distance.

Annex 1 addresses the determination of points for the determination of potential interference from ESVs. Once this determination has been made, it is necessary to consider interference into stations beyond the radio horizon as well as interference into stations that have line-of-sight coupling to the operating positions of an ESV in motion. In the case of fixed transmitting earth stations, the interference into FS receivers beyond the horizon is limited by applying short-term interference criteria, and interference into receivers with line-of-sight coupling is limited by applying long-term interference criteria. Recommendation ITU-R SF.1006 provides the methodology and interference criteria for both long- and short-term interference assessment and recommends that both criteria be met in the determination of interference potential. While ESVs add complexity to the determination of interference potential, the principles remain the same: distant stations are protected from short-duration high-power interference by short-term criteria; nearby stations are protected by long-term criteria, which protect the fade margin of the receiver. This Annex provides the basis for determining the interference potential in all cases of interest.

Section 2 below describes the statistics of the propagation loss between two stations on the surface of the Earth, and shows, for different length paths, the relation between the loss exceeded for all but a percentage of the time and the long- and short-term interference criteria that are applied when the transmitting earth station is at a fixed location. Section 3 considers how to determine the interference potential in the presence of the additional complexity caused by introducing motion to the position of the interfering station and develops an approach derived from the use of the Fractional Degradation of Performance (FDP) approach of Recommendation ITU-R F.1108 in conjunction with the critical contour point (CCP) methodology of Annex 1 to this Recommendation. It is shown in Section 4 that this approach leads to a method for determining the acceptability of the potential interference based on existing long-term interference criteria. An approach to the consideration of short-term interference based on the same set of CCPs is developed in Section 5.

2 Minimum required propagation loss for a fixed percentage of time with stationary stations

The minimum required propagation loss required to meet a permissible level of interference power at the antenna terminals of a receiving fixed station for a percentage of time *p* may be obtained with Recommendation ITU-R SM.1448, where the minimum required loss is the loss that needs to be equalled or exceeded by the predicted path loss for all but *p*% of the time*. Thus,

$$L_b(p) = P_t + G_t + G_r - P_r(p) \qquad \text{dB} \qquad (1)$$

where:

- p: the maximum percentage of time for which the permissible interference power may be exceeded
- $L_b(p)$: the propagation mode (1) minimum required loss (dB) for *p*% of the time; this value must be exceeded by the propagation mode (1) predicted path loss for all but *p*% of the time
- P_t: the maximum available transmitting power level (dBW) in the reference bandwidth at the terminals of the antenna of a transmitting terrestrial station or earth station
- $P_r(p)$: permissible interference power of an interfering emission (dBW) in the reference bandwidth to be exceeded for no more than *p*% of the time at the terminals of the antenna of a receiving terrestrial station that may be subject to interference, where the interfering emission originates from a single source
- G_t: the gain (dB relative to isotropic) of the antenna of the transmitting terrestrial station or earth station. For a transmitting earth station, this is the antenna gain towards the physical horizon on a given azimuth
- G_r: the gain (dB relative to isotropic) of the receiving antenna of the terrestrial station or earth station that may be subject to interference. For a receiving terrestrial station, the maximum main beam axis antenna gain is to be used.

For long-term interference, the percentage of time is usually taken as 20 percent and the permissible interference power is given, in accordance with Recommendation ITU-R SF.1006 as:

$$P_r(20) = 10 \log (k\, T_e\, B) + J \qquad \text{dBW} \qquad (2)$$

where:

- k: Boltzmann's constant, 1.38×10^{-23} J/K
- T_e: the thermal noise temperature of the receiving system (K), at the terminal of the receiving antenna
- B: the reference bandwidth (Hz), i.e. the bandwidth in the receiving station that is subject to the interference and over which the power of the interfering emission can be averaged
- J: ratio (dB) of the permissible long-term interfering power from any one interfering source to the thermal noise of the receiving system.

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* When *p* is a small percentage of the time, in the range 0.001% to 1.0%, the interference is referred to as "short term"; if $p \geq 20\%$, it is referred to as "long term".

For short-term interference, the percentage of time is an appropriate portion of the total percentage of time allowed for interference. For the purpose of the present discussion, we take the percentage as 0.001%, and write:

$$P_r\,(0.001) = 10 \log (k\,T_e\,B) + 10 \log (10^{M_s/10} - 1) \qquad \text{dBW} \qquad (3)$$

where:

M_s: link performance margin (dB).

Note that the permissible power for short-term interference is significantly larger than the permissible power for long-term interference. That is,

$$P_r\,(0.001) - P_r\,(20) = 10 \log (10^{M_s/10} - 1) - J \qquad \text{dB} \qquad (4)$$

Recommendation ITU-R SF.[4-9S/ESV-A] used a value of 19 dB for M_s in developing a short-term permissible interference power. Assuming –10 dB as a representative value for J, the difference in equation (4) would be:

$$P_r\,(0.001) - P_r\,(20) \approx 29 \qquad \text{dB} \qquad (5)$$

These permissible interference powers can be used in equation (1) to determine minimum required propagation loss, which must be exceeded by the predicted path loss for all but the same percentage of time. The predicted path loss that is exceeded for all but a percentage of time p may be calculated by the procedure in Recommendation ITU-R P.452, and denoted as $L_{452}\,(p)$. The dependence with distance of the predicted path loss exceeded for all but 20 per cent of the time and for all but 0.001 per cent of the time typically appears as shown in Figure 1.

For the chosen antenna heights, the propagation path from the interfering source to the FS receiver is just grazing at the path distance d_h. At larger distances the receiver is beyond the radio horizon and the predicted loss exceeded for all but 20 per cent of the time, $L_{452}(20)$, increases rapidly with distance. At the critical distance d_c , the difference between the predicted loss exceeded for all but 20 per cent of the time is larger than that exceeded for 0.001 per cent of the time by 29 dB. Hence at this distance, the long-term and the short-term interference criteria for these time percentages are both met or neither is met. At larger distances the long-term interference criterion is always met if the short-term criterion is met. At shorter distances the short-term interference criterion is always met if the long-term criterion is met. It is for this reason that only short-term interference criteria are used in the determination of coordination area.

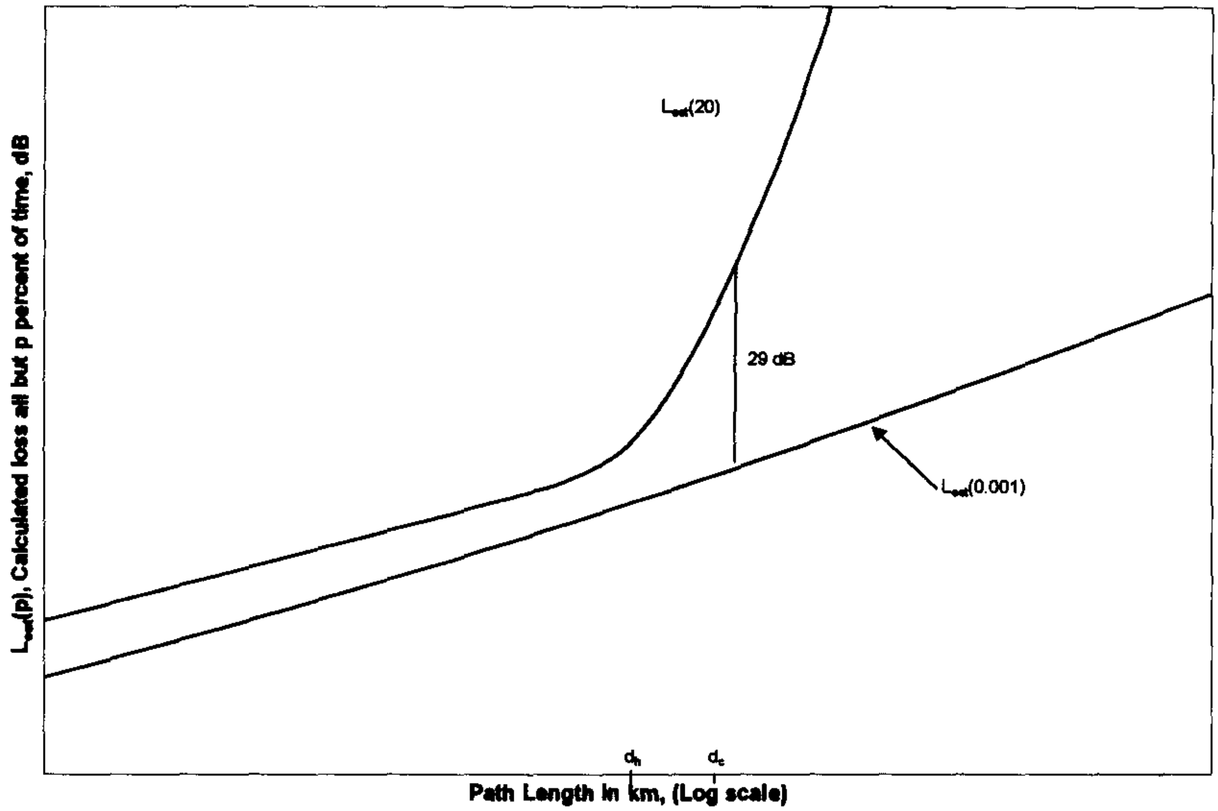

FIGURE 1

Distance dependence of the predicted path loss for all but 20 per cent and 0.001 per cent of the time (estimated)

3 Implications of time-variations in parameters other than propagation loss

In the case of ESVs, the interfering power at the receiving antenna is subject to changes in received power due to movement of the transmitting earth station as well as those due to a propagation loss that changes with time. The considerations for long-term and short-term interference can be addressed by adapting techniques used in other sharing scenarios. The separate treatments that are necessary for the consideration of short-term and long-term interference for ESVs in motion are provided in the following subsections.

3.1 Short-term interference consideration

The considerations of short-term interference from ESVs are not unlike, although more complex than, those used for the determination of coordination area for a receiving fixed station with respect to earth stations operating to non-GSO space stations. For the non-GSO case, only the horizon gain (G_t), shown above in equation (1), varies with time. The Time-Varying Gain (TVG) method in § 2.2.1 of Recommendation ITU-R SM.1448 is suggested as a supplementary method for these scenarios (see also Recommendation ITU-R SF.1485). The application of the TVG method requires the determination of the cumulative distribution of the horizon gain in the direction of the fixed station exceeded for percentages of time (p_n). For each percentage p_n the associated horizon gain and the permissible interference power ($P_t(p)$) are used in equation (1), above, to determine a minimum required loss that should be exceeded for all but p_v per cent of the time, with the constraint:

$$p_v = \begin{cases} 100\, p / p_n & \text{for } p_n \geq 2\,p \\ 50 & \text{for } p_n < 2\,p \end{cases} \quad \text{per cent} \tag{6}$$

The predicted path loss for p_v per cent of the time must exceed this loss for each p_n at the coordination distance, in the determination of coordination area.

The ESV case is more complex in that the interfering path from the ESV to the fixed station also changes as the vessel moves. Thus, there is no unique association with the percentages p_n and the Gains (G_n). For the determination of interference potential, it is necessary to consider a number of points along the operating contour of the ESV as critical contour points and to associate a transmit antenna horizon gain and a percentage of time with each of these points.

3.2 Long-term interference consideration

The consideration of long-term interference from ESVs is necessary only for the determination of interference potential. This scenario is not unlike the scenarios of space-to-earth interference from non-GSO satellites into FS receivers, for which the concept of Fractional Degradation of Performance (FDP) was developed. Recommendation ITU-R F.1108 defines FDP as:

$$\text{FDP} = \frac{\sum_i f_i I_i}{N_T} = \frac{\text{Average Interference Power}}{\text{N}_\text{T}} \tag{7}$$

where:

- N_T: the effective noise power at the receiver input (dBW/B)
- I_i: the ith level of interference power present at the receiver input (dBW/B)
- f_i: the fraction of time that the ith interference level is present
- B: a reference bandwidth.

In the case of interference from non-GSO satellites, it is usually assumed that the satellite emissions propagate under free-space conditions, although atmospheric losses have been included in some cases. Thus, the FDP is determined with equation (7) by using a simulation to obtain the values of interference power and the fraction of time for which they occur. In considering interference between fixed terrestrial stations and fixed earth stations, the usual procedure is to use a propagation model such as that of Recommendation ITU-R P.452 for the determination of propagation loss. A composite approach can be developed by using Recommendation ITU-R P.452 to determine the propagation loss, exceeded for all but 20 per cent of the time, to a critical contour point. By scaling this loss in accordance with the distance-squared dependence of the free-space loss, the contribution to the FDP from operations along portions of the track of an ESV can be determined in closed form by direct integration. To conform more closely to the methodology used with earth stations for the determination of interference potential, the interference potential will be determined on the basis of the average interference power - the numerator of the expression in equation (7). This average power can be compared directly with the permissible value of long-term interference. The approach is described more fully in section 4.

4 Detailed consideration of long-term interference

To consider the long-term interference from ESVs operating on a proposed contour within the off-shore distance, it is first necessary to break the operating contour into a set of straight-line segments. The ends of these straight-line segments provide the basis for the determination of all of the critical contour points defined using the method of Annex 1 needed to determine the average interference power. In the cases where the main-beam axis of the fixed service antenna intersects one of the segments, the intersection point is also a critical contour point for that FS station. The average interference power is developed as the sum of the contributions from each segment of the operating contour. Following the usage and notation of Recommendation ITU-R SF.[4-9S/ESV-A], it is assumed that f_{ESV} vessels per year traverse the operating contour, each at a constant speed of v_{ESV} km/hour.

When a segment contains an intersection with the main-beam axis of the FS antenna, the contribution due to the passage of the ESV through the main beam is likely to dominate the contribution from that segment to the average interference power. The contributions due to a main-beam passage and due to passage through a segment that has no main-beam axis intersection are considered in the following two subsections, respectively. The overall procedure for including all contributions to the average interference power is contained in a third subsection.

4.1 Contribution from a main-beam passage to the average interference power

Recommendation ITU-R F.699 or F.1245 may be used to provide the functional form of the fixed service antenna gain (dBi) at an angle of ϕ_d degrees from boresight as:

$$G_r(\phi_d) = G_{\max} - 2.5\times10^{-3}\left(\frac{D}{\lambda}\right)^2 \phi_d^2 \qquad \text{for} \quad \phi_d < \phi_{dm}$$

where:

$$\frac{D}{\lambda} = 10^{(G_{\max}-7.7)/20}: \text{ ratio of antenna diameter to wavelength}$$

$$\phi_{dm} = \frac{20\lambda}{D}\sqrt{G_{\max} - G_1}: \text{ the off-boresight angle to the first sidelobe (degrees)}$$

$$G_1 = 2 + 15\log(D/\lambda): \text{ the antenna gain at the first side lobe (dBi).}$$

Then the gain ratio in the main beam within an angle of ϕ_r degrees from boresight is given by[2]

$$g_r(\phi_r) = g_{\max}\, e^{-\alpha^2\phi_r^2} \qquad \text{for } \phi_r < \phi_{dm} \tag{8}$$

with:

$$\alpha^2 = \frac{\ln(10)}{10}(2.5\times10^{-3})\left(\frac{D}{\lambda}\right)^2$$

2 Throughout these developments, quantities in dB, dBi or dBW are identified by capital roman italic symbols. The same quantities, when expressed in power ratios or power units, are denoted by the lower case form of the same roman italic symbols with the same subscript. Thus, $g_{\max} = 10^{G_{\max}/10} = e^{G_{\max}\ln(10)/10}$.

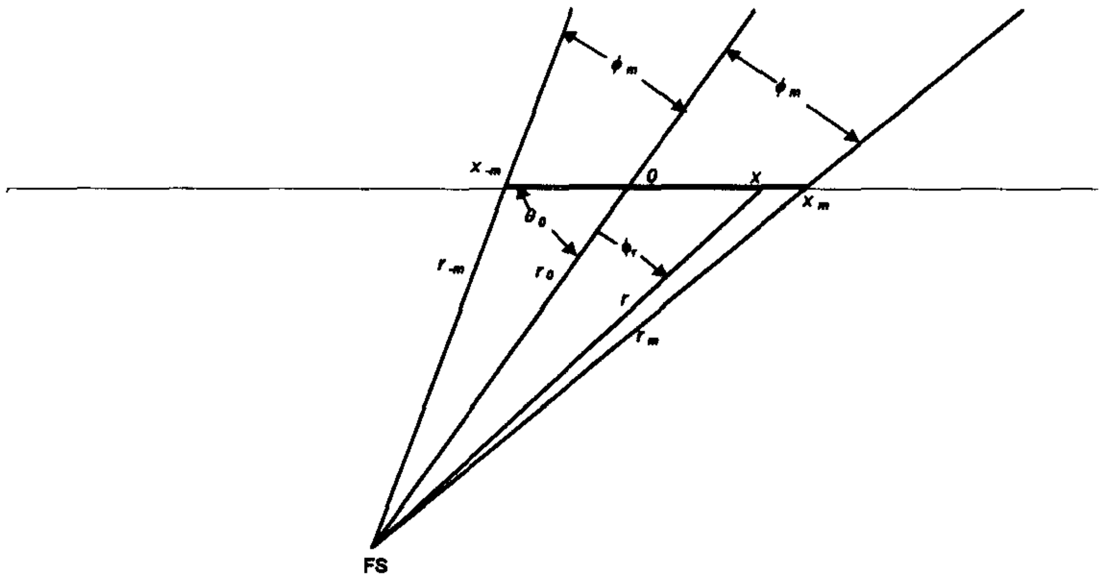

FIGURE 2

Geometry of a main-beam passage of an ESV

The geometry of the main-beam passage is shown in Figure 2. The operating route for the ESV is along the x-axis, which crosses the main beam axis at x = 0 with an angle θ_0. The main beam of the antenna has a −10 dB beamwidth (2 ϕ_m) of less than 2 degrees for an antenna with a maximum gain of 45 dBi which is representative for the 6 GHz band. The main beam intersects the ESV track over the range of x between x_{-m} and x_m. The received power (Watts in the reference bandwidth) received when the ESV is displaced from the point where the main-beam axis crosses the ESV track by x km, and from the FS receiver by r km, may be written as:

$$p_{r,x} = \frac{p_t \, g_{t0} \, g_{r\max}}{\ell_{452.0}(20) \, \ell_F} \frac{r_0^2}{r^2} e^{-\alpha^2 \phi_r^2} \qquad (9)$$

where:

- p_t: the transmit power in Watts in the reference bandwidth
- g_{t0}: the transmit antenna gain (as a ratio) toward the FS receiver when the ESV is at the beam intersection
- g_{rmax}: the maximum gain (as a ratio) of the receiving antenna
- ℓ_F: the feeder loss ratio of the FS receiving system
- $\ell_{452.0}\,(20)$: the propagation loss ratio to the beam intersection, as calculated with Recommendation ITU-R P.452, that will be exceeded for all but 20 per cent of the time

ϕ_r : the off-main-beam axis angle in degrees

ϕ_m : the off-main-beam axis angle in degrees for which the gain of the receiving antenna is 10 dB below its maximum.

Note that the transmit antenna gain is assumed to be constant over the narrow (less than 2 degree) angular region, and the propagation loss has been scaled for the distance r.

Since the half-width of the main beam is less than 1 degree, one can write approximately:

$$r = r_0 + x\cos\theta_0$$

$$\phi_r = (180/\pi)x\sin\theta_0/(r_0 + x\cos\theta_0)$$

The mean value of the interference power for a transmitter uniformly distributed over the route from x_{-m} to x_m is:

$$\overline{p_{r,0}} = \frac{1}{x_m - x_{-m}}\int_{x_{-m}}^{x_m} p_{r,x}dx$$

where $p_{r,x}$ is given by equation (9). With a change in the variable of integration to ϕ_r, this becomes:

$$\overline{p_{r,0}} = \frac{p_t\, g_{t0}\, g_{r\max}}{\ell_{452.0}(20)\, \ell_F}\frac{2\phi_m r_0(\pi/180)}{(x_m - x_{-m})\sin\theta_0}\left[\frac{1}{2\phi_m}\int_{-\phi_m}^{\phi_m} e^{-\alpha^2\phi_r^2}d\phi_r\right] \qquad (10)$$

The term in square brackets is the average gain relative to g_{rmax} (as a ratio) of the main beam measured between the angles where the gain is 10 dB below the maximum gain. For the reference antenna pattern of Recommendation ITU-R F.699 or F.1245, this quantity has a value of 0.565.

The average given by equation (10) may be converted to an average aggregate power over a year by multiplying by the fraction of a year that this average interference power is present. The time in hours for a vessel to pass through the main beam is $(x_m - x_{-m})/v_{ESV}$. If the number of vessels per year passing through the main beam is f_{ESV}, the aggregate average interference power averaged over a year is given by*:

$$\tilde{I}_{0,av} = \frac{p_t\, g_{t0}\, g_{r\max}}{\ell_{452.0}(20)\, \ell_F}\frac{2\pi\phi_m r_0}{180\, v_{ESV}\sin\vartheta_0}\frac{f_{ESV}}{8760}(0.565) \qquad (11)$$

where 8 760 is the number of hours in a year.

Note that the average long-term interference power is significantly lower than that which would be ascribed to an earth station with the same characteristics if it were permanently located at the point where the FS antenna main-beam axis crosses the operating track of the ESV. For instance, with a 90 degree crossing angle, which generates the least interference, and with 1000 passes of a vessel at a speed of 5 knots (9.261 km/hr) at a distance of 20 km, the average interference power given by equation (11) would be 23.8 dB lower. For the same situation, except with a crossing angle of 20 degrees, the average would be only 19.1 dB lower. Of course, contributions from ESV operation on other portions of the operating route would need to be taken into account as they would further reduce this dB difference. Even if these other contributions could be neglected, it is not clear

* The tilde (~) above the symbol for the average interference power is used as a reminder that this quantity is a power with units of Watts in the reference bandwidth.

whether the long-term or the short-term criteria would be controlling for this case, given that the short-term criteria would be applied to the interference power at the main beam axis intersection with the operating contour. It is for this reason that both the short-term and the long-term interference criteria must be applied for ESVs in motion.

4.2 Contribution to the average interference power from a segment without a main-beam intersection

The geometry and co-ordinates for this case are shown in Figure 3. The vessel traverses a segment of the operating contour between x_a and x_b. The formulation is similar to that of equation (9), except that the length of the segment may be much longer than a beamwidth passage. Consequently, in this case the horizon gain of the ESV is replaced by its maximum value on the azimuth to the FS receiver as it passes through the segment. While the actual gain pattern of the FS antenna could be included in an integration, a simpler approach is to assume that the FS gain in dBi varies linearly with the azimuth angle between ϕ_a and ϕ_b. Note that the azimuth angles in this formulation are measured from the perpendicular dropped from the FS station location to the line containing the segment from x_a to x_b. The linear approximation is conservative in that the reference antenna gain patterns outside the main beam are either flat or concave upward; it will not degrade the accuracy of the results because the difference in the gain from one end of the segment to the other is not usually large. Accordingly, the received power (in Watts in the reference bandwidth) when the ESV is on such a segment at a distance x from the intersection of the perpendicular dropped from the FS station to the line containing the segment is given as:

$$p_{r,x} = \frac{p_t\, g_{t,ab}}{\ell_{452.a}(20)\, \ell_F} \; \frac{r_a^2\, g_{r\phi_r}}{r_{\perp ab}^2 + x^2} \tag{12}$$

where:

- p_t: the transmit power in Watts in the reference bandwidth
- $g_{t,ab}$: the maximum transmit antenna gain ratio toward the FS receiver when the ESV is between x_a and x_b
- ℓ_F: the feeder loss ratio of the FS receiving system
- $\ell_{452.a}(20)$: the propagation loss ratio to the point x_a, as calculated with Recommendation ITU-R P.452, that will be exceeded for all but 20 per cent of the time
- $g_{r\phi_r}$: the gain (as a ratio) of the receiving antenna on the azimuth ϕ_r to the point x
- $r_{\perp ab}$: distance from the FS station to the line containing the segment from x_a to x_b.

Under the assumption that the gain of the receiving antenna, in dB, varies linearly from G_a at ϕ_{ra} to G_b at ϕ_{rb}, the gain ratio $g_{r\phi_r}$ can be written as:

$$g_{r\phi_r} = g_{ra}\, e^{\frac{\ln(10)}{10}\left(\frac{G_{rb} - G_{ra}}{\phi_{rb} - \phi_{ra}}\right)(\phi_r - \phi_{ra})} \tag{13}$$

The mean value of the interference power $\overline{p_{r,ab}}$ over the segment may be developed as in equation (10) by integrating equation (12) over the interval x_a to x_b and dividing by the interval length. Changing the variable of integration to ϕ_r where $x = r_{\perp ab} \tan(\pi \phi_r / 180)$ one finds:

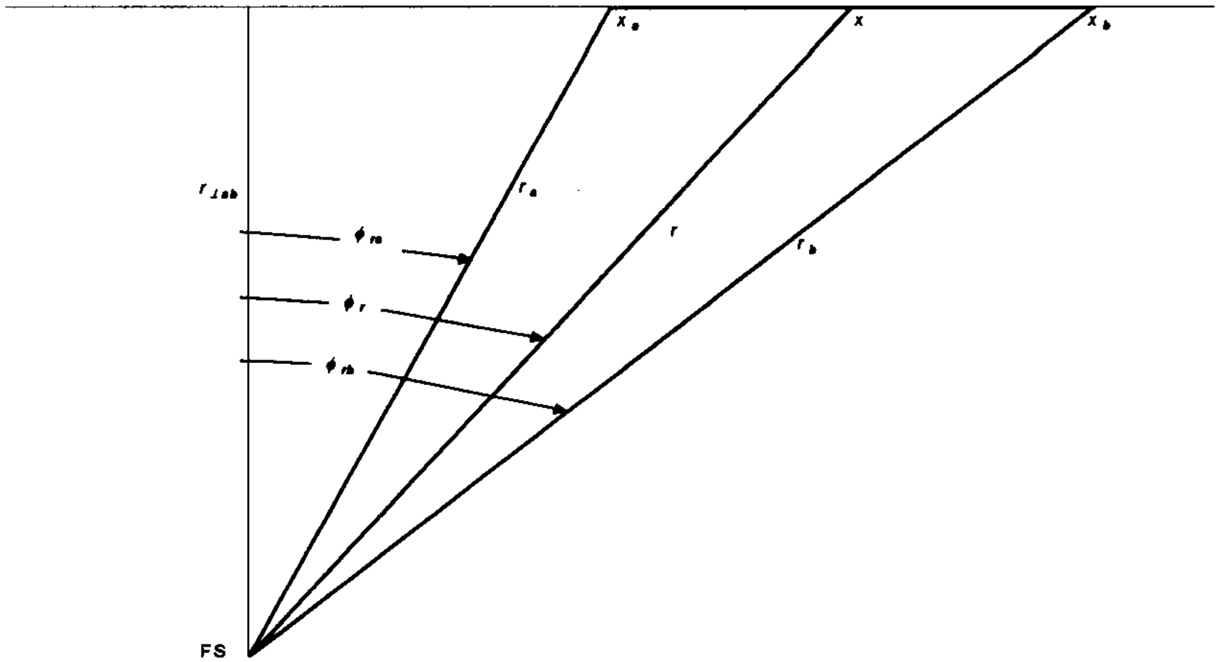

FIGURE 3

Geometry of the passage of an ESV through a segment of an operating contour outside of the main-beam of the FS antenna

$$\overline{p_{r,ab}} = \frac{p_t g_{t,ab}}{\ell_{452.a}(20)\ \ell_F} \frac{\pi r_a^2 (\phi_{rb} - \phi_{ra}) \sqrt{g_{ra} g_{rb}}}{180 r_{\perp ab}(x_b - x_a)} \operatorname{sinch}((G_b - G_a)\ln(10)/20) \tag{14}$$

where the angles ϕ_{ra} and ϕ_{rb} are expressed in degrees:

$$\operatorname{sinch}(x) = \frac{\sinh(x)}{x}$$

The time in hours for a vessel to pass through this segment of the operating route of an ESV is $(x_b - x_a)/v_{ESV}$. If the number of vessels per year passing through the main beam is f_{ESV}, the aggregate average interference power from the segment, averaged over a year, is given by:

$$\tilde{I}_{ab,av} = \frac{p_t\, g_{t,ab} \sqrt{g_{ra} g_{rb}}}{\ell_{452.a}(20)\ \ell_F} \frac{\pi r_a^2 (\phi_{rb} - \phi_{ra}) f_{ESV}}{180 r_{\perp ab} 8760 v_{ESV}} \operatorname{sinch}\left((G_{rb} - G_{ra})\ln(10)/20\right) \tag{15}$$

The evidence that this development began with an expansion of the propagation loss factor at the point x_a resides in the term $r_a^2 / \ell_{452.a}(20)$ in equation (15). If the average interference power had been determined from the propagation loss factor at the point x_b, the average interference power would be identical except for the replacement of $r_a^2 / \ell_{452.a}(20)$ by $r_b^2 / \ell_{452.b}(20)$. If the propagation loss factor exceeded for all but 20 per cent of the time varied inversely with the square of the distance, these two terms would also be identical. A simple approach that compensates for the deviation from the inverse square-law dependence is to average the two calculations, which gives:

$$\tilde{I}_{ab,av} = \frac{p_t\, g_{t,ab} \sqrt{g_{ra} g_{rb}}}{2\,\ell_F} \frac{\pi(\phi_{rb} - \phi_{ra}) f_{ESV}}{180 r_{\perp ab} 8760 v_{ESV}} \left(\frac{r_a^2}{\ell_{452.a}(20)} + \frac{r_b^2}{\ell_{452.b}(20)} \right) \operatorname{sinch}\left((G_{rb} - G_{ra}) \ln(10)/20 \right) \quad (16)$$

4.3 Aggregate average interference power from an operating contour

The critical contour points are identified by breaking the operating contour of the ESV into straight-line segments and locating the geographic locations of the points where the ends of segments join together. After finding the azimuth to each of these critical points from a given FS receiver, it can easily be determined whether the main-beam axis of the FS antenna intersects any segment.

If no main-beam intersections occur, the average value of the potential interference can be determined by summing the contribution from each segment of the operating contour using equation (16).

If there is a main-beam intersection on one of the segments, there will be one, two or three contributions to the total average interference potential from operations on that intersected segment. These contributions are added to the partial sum developed from the contributions of each of the remaining segments as calculated by equation (16).

The three possible contributions from the intersected segment are determined as follows:

– A contribution corresponding to the main-beam passage is determined by applying equation (11). If this segment lies entirely within the main beam of the FS antenna, this is the only contribution from this segment.

– The contribution from the portion(s) of this segment outside the main beam of the FS antenna may be determined using equation (16) by identifying additional Critical Contour Point(s) at the edge of the main beam.

Throughout these discussions, it has been assumed that the horizon gain of the ESV transmit antenna does not have a strong variation with azimuth. The procedure can be easily modified to accommodate for variation in the horizon gain with azimuth. When neither antenna gain has a maximum for an ESV position within a segment, the gain averaging that was applied to the receive gain in § 4.2 can be applied to the product of the transmit and receive gain ratios. In this case equation (16) becomes

$$\tilde{I}_{ab,av} = \frac{p_t \sqrt{g_{ta} g_{ra} g_{tb} g_{rb}}}{2\,\ell_F} \frac{\pi(\phi_{rb} - \phi_{ra}) f_{ESV}}{180 r_{\perp ab} 8760 v_{ESV}} \left(\frac{r_a^2}{\ell_{452.a}(20)} + \frac{r_b^2}{\ell_{452.b}(20)} \right) \times$$

$$\operatorname{sinch}\left((G_{tb} + G_{rb} - G_{ta} - G_{ra}) \ln(10)/20 \right) \quad (17)$$

where:

g_{ta}: the transmit antenna gain ratio toward the FS receiver when the ESV is at the CCP at x_a

g_{tb}: the transmit antenna gain ratio toward the FS receiver when the ESV is at the CCP at x_b.

Alternatively, when the transmit antenna gain has a maximum with respect to a FS receiver when the ESV passes through a segment and the receive gain does not, a more accurate result can be obtained by defining the point on the segment where a particular FS receiver experiences the maximum as an additional critical contour point to be used to determine the interference potential to that receiver.

5 Detailed consideration of short-term interference

The considerations of the short-term potential interference from ESVs differ in two significant respects from the short-term interference considerations used in the determination of the offshore distance beyond which interference from ESVs need not be considered. In determining the off-shore distance, consideration was limited to cases where the ESV crossed through the main-beam axis of the FS receiving antenna. Consideration was further limited to the case where the crossing track was perpendicular to the main-beam axis. The short-term considerations developed in this section accommodate all of the possibilities and, hence, will parallel the development in the preceding section.

In considering the potential for short-term interference to a fixed service receiver from an ESV on its operating contour, it is necessary to determine a short-term potential interference power from each of the critical points on that contour in order to determine which point controls the short-term interference. In the following development, it will be assumed that there is a single critical point that determines the potential interference power, which is exceeded for a specified percentage of the time and can be compared to the short-term interference criterion. Because of the inter-relations between the parameters, a direct identification of the controlling point and the associated power cannot usually be made directly. While several approaches are possible, the one in this section appears to be the most direct.

For convenience in the following developments, the critical contour point determined by a main-beam crossing, when such a crossing exists, will be designated by the number 0. The remaining critical contour points, which identify the points where the operating contour changes direction, will be numbered in sequence along the contour from 1 to N_{CCP}, where N_{CCP} is the number of such critical contour points on the operating route of the ESV. In accordance with the discussion in § 3.1 and in conformance with the developments in § 4, the power at the FS receiver (in dBW) that is exceeded for p_{ST} per cent of the time when the ESV is operating near the *i*th critical contour point is given as:

$$I_{ST,i}(p_{ST}) = P_t + G_{t,i} + G_{r,i} - L_F - L_{452,i}(p_{Li}) \tag{18}$$

where:

- p_{ST}: the percentage of time for which the permissible power level for short-term interference (see equation (3)) may be exceeded
- P_t: the transmit power in dBW in the reference bandwidth
- $G_{t,i}$: the transmit antenna gain toward the FS receiver when the ESV is at the *i*th critical contour point, for $i = 1$ *to* N_{ccp} (dBi)
- $G_{r,i}$: the gain of the receiving antenna toward the ESV when the ESV is at the *i*th critical contour point, for $i = 1$ *to* N_{ccp} (dBi)
- L_F: the feeder loss of the FS receiving system (dB)
- $L_{452,i}(p_{Li})$: the propagation loss to the *i*th critical contour point, as calculated with Recommendation ITU-R P.452, that will be exceeded for all but p_{Li} percent of the time, for $i = 1$ *to* N_{ccp} (dB).

The percentage of time, p_{Li}, is given by:

$$p_{Li} = 100 p_{ST} / p_{ESVi} \tag{19}$$

where:

p_{ESVi}: the per cent of time associated with the ESV operation near the ith critical contour point.

In the case of a main-beam crossing, a direct evaluation of the necessary values is possible. The percentage of time associated with the ESV operation near the main-beam crossing is the time to cross the main-beam of the FS antenna at a specified gain level relative to the maximum gain. In Recommendation ITU-R SF. [4-9S/ESV-A] and in § 4 above a 10 dB width was used. For consistency the same width should be used for the determination of the short-term interference potential. Using the 10 dB beamwidth as the basis for calculating the percentages p_{ESV0},

$$p_{ESV0} = 4 \times 10^{-4} \frac{f_{ESV}\,\phi_m\,r_0}{v_{ESV} \sin\theta_0} \tag{20}$$

where the symbols were defined in deriving equation (11).

Using equations (18)-(20), one can determine $I_{ST,0}$, the value of the power at the FS receiver that is exceeded for p_{ST} per cent of the time due to operation of the ESV in the main beam of the FS antenna. Although there may be areas close to another critical point on the operating route of the ESV, which could lead to the determination of a short-term power that would be almost as high for the same percentage of time, only a single worst-case maximum power will be considered. The alternative would be to partition the permissible percentage of time, p_{ST}, between these critical contour points.

In order to determine the potential interference power from a critical contour point that is not the result of the intersection of the main beam with a segment of the operating contour, one must first determine the associated percentage of time that the ESV operates close to that CCP. The most direct and conservative approach is to associate with a given CCP half of each of both adjacent operating segments. Thus, denoting by $x_{i,i+1}$ the length of the segment between the CCP numbered i and an adjacent CCP numbered $(i+1)$, the percentage of time associated with this CCP is:

$$p_{ESVi} = \text{Lesser of } \frac{f_{ESV}}{87.6 v_{ESV}} \frac{(x_{i,i-1} + x_{i,i+1})}{2} \text{ and } 100 \text{ per cent} \tag{21}$$

The values of each of the critical short-term potential interference powers can be determined ($i \neq 0$) using equations (21) and (19) with (18). The largest of these short-term powers is the controlling power to be used in comparison with the permissible short-term interference power.

6 Summary

This Annex describes a set of procedures that can be used to determine the interference potential of emissions from an ESV operating on a prescribed contour near land.

Although this procedure concentrates on the 6 GHz band, the same approach may also be applicable to the 14 GHz band, which is also addressed in Resolution 82 (WRC-2000). The performance of fixed service links in the 14 GHz band is affected by multipath fading and by precipitation fading, and the relative importance of the two mechanisms depends on the radiometeorological climate. With other considerations constant, sharing conditions are more restrictive when multipath fading controls the performance of a fixed service link. Hence this procedure should also be appropriate for the 14 GHz band.

The table of parameters to be used as guidance in applying the method may be found in Recommendation ITU-R [4-9S/ESV-A]. The parameters for ESVs should represent the actual system parameters, which should conform to those in Recommendation ITU-R S.[4/57 Rev.1]. The parameters for fixed links should also represent the actual system parameters. Regarding the interference criteria, Recommendations ITU-R SF.1006 and SF.[ESV-A] may be referred to.

ANNEX 3

Alternative method for calculation of interference from earth stations on board vessels

1 Introduction

This Annex describes a set of procedures by which the method in Annex 2 can be modified so that it can be implemented using simulation techniques. These procedures may require additional computing time, but may lead to more accurate results.

2 Simulation Procedure

Initially, the operating contour is subdivided into a large number R of small straight-line segments $\Delta\vec{r}_i$ centered at $\vec{r}_i$ ($I = 1, 2, \ldots, R$) in such a way that the length of the segments remains constant.

From the discrete version of the total probability theorem, one has

$$\Pr\{p_{\text{int}} > I\} = \sum_{i=0}^{R} \Pr\{p_{\text{int}} > I \mid (\vec{r}_i - \Delta\vec{r}_i/2,\ \vec{r}_i + \Delta\vec{r}_i/2]\} \cdot \Pr\{(\vec{r}_i - \Delta\vec{r}_i/2,\ \vec{r}_i + \Delta\vec{r}_i/2] \qquad (1)$$

In equation (1), $\Pr\{p_{\text{int}} > I\}$ is the probability that the level I (dBW) of the interference power be exceeded; $\Pr\{p_{\text{int}} > I \mid (\vec{r}_i - \Delta\vec{r}_i/2,\ \vec{r}_i + \Delta\vec{r}_i/2]$ is the same probability, conditioned to the positioning of the ESV within the interval $(\vec{r}_i - \Delta\vec{r}_i/2, \vec{r}_i + \Delta\vec{r}_i/2]$; and $\Pr\{(\vec{r}_i - \Delta\vec{r}_i/2,\ \vec{r}_i + \Delta\vec{r}_i/2]$ is the probability of the interval in the operating contour. Assuming that the ESV velocity v_{ESV} remains constant in the operating contour, that the number of vessels per year passing through the operating contour is f_{ESV}, and since all the intervals have the same probability, it follows that

$$\Pr\{(\vec{r}_i - \Delta\vec{r}_i/2, \vec{r}_i + \Delta\vec{r}_i/2]\} = \frac{f_{ESV} \cdot \Delta t}{365 \cdot 24 \cdot 3600} = \frac{f_{ESV} \cdot \Delta t}{31536000} \qquad (2)$$

where $\Delta t = |\Delta\vec{r}_i| / v_{ESV}$. Combining equations (1) and (2), and remembering that the segments are small, one gets the basic equation of the simulation procedure

$$\Pr\{p_{int} > I\} \approx \frac{f_{ESV} \cdot \Delta t}{31536000} \sum_{i=0}^{R} \Pr\{p_{int} > I \mid \vec{r} = \vec{r}_i \tag{3}$$

Equation (3) indicates that $\Pr\{p_{int} > I \mid \vec{r} = \vec{r}_i\} = p/100$ should be evaluated at each point $\vec{r}_i$ of the operating contour, the partial values accumulated and the results scaled to produce the probability that the level I (dBW) of the interference power be exceeded. This procedure is then repeated for all the levels I (dBW) of interest. Using straightforward notation, one can write

$$I = P_{ESV} + G_{ESV}(\theta_{ESV}) + G_{FS}(\theta_{FS}) - L_{FS} - L_{P.452,i}(p) \tag{4}$$

In equation (4), which is analogous to equation (18) in Annex 2, $L_{452.i}(p)$ is the propagation loss in the interference path characterized by the ESV located at $\vec{r}_i$ and by the FS receiver, as calculated with Recommendation ITU-R P.452-9. In the present simulation, equation (4) is inverted (either analytically or numerically, depending on the path type) to yield the value of p (%) related to the given value of I (dBW) and to the particular location $\vec{r}_i$ of the ESV that is used in the right hand side of equation (3).

ATTACHMENT 4

INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

Document 4/91-E
Document 9/150-E
25 April 2002
English only

Source: Document 4-9S/TEMP/111

Working Party 4-9S

DRAFT NEW RECOMMENDATION
ITU-R SF.[4-9S/ESV-FREQ]*

Use of frequencies by earth stations on board vessels transmitting in certain bands allocated to the fixed-satellite service

(Questions ITU-R 254/4 and ITU-R 226/9)

The ITU Radiocommunication Assembly,

considering

a) that Resolution 82 (WRC-2000) resolved to invite ITU-R, as a matter of urgency, to study, as a complement to the 3 700-4 200 MHz and 5 925-6 425 MHz bands, the use of other fixed-satellite service (FSS) allocations for earth stations on board vessels (ESVs) transmitting in the 6 GHz and 14 GHz bands;

b) that the band 13.75-14.5 GHz is allocated to the FSS (Earth-to-space) on a worldwide basis;

c) that the current use of the band 13.75-14.0 GHz by the radiolocation service for maritime applications may not be technically compatible with the operation of ESVs;

d) that the band 14.3-14.5 GHz is also allocated to the fixed and mobile (except aeronautical mobile) services and some allocations in this band are on a regional basis;

e) that **No. 5.505** of the Radio Regulations makes an additional allocation of the band 14.0-14.3 GHz to the fixed service (FS) in a number of countries and that **No. 5.508** of the Radio Regulations makes an additional allocation of the band 14.25-14.3 GHz to the FS in a number of countries;

f) that the band 14.0-14.3 GHz is also allocated to the radionavigation service;

g) that the use of the band 6 425-6 725 MHz by remote sensors for passive microwave sensor measurements, operating under No. 5.458, needs to be reviewed;

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* This Recommendation should be brought to the attention of ITU-R Study Group 8 (WP 8D).

h) that, when planning to operate within the distances of Recommendation ITU-R SF.[ESV-A], the probability of obtaining the agreement of affected administrations may be increased if ESVs operate in bands not shared with terrestrial services;

j) that where, in a given region, there is little use of certain bands within the range 14-14.5 GHz by terrestrial services the probability of obtaining approval for ESV operation within the "minimum distance"[1] within that region, would be increased by selecting frequencies within those lightly used bands;

k) that the service areas of existing geostationary FSS satellites operating in the 14 GHz band are not global,

recommends

1 that the bands 5 925-6 425 MHz and 14–14.5 GHz may be suitable for ESV operation (Earth-to-space) from a technical point-of-view (NOTE 1);

2 that the agreement of potentially affected administrations be obtained before ESVs operate within the "minimum distances"* in Recommendation ITU-R SF.[ESV-A].

NOTE 1 – The band 6 425–6 725 MHz is also allocated to the FSS. However the suitability of this band for ESV (Earth-to-space) needs further study due to some different sharing conditions arising from other services which may exist in this band and the corresponding downlink band (3 400-3 700 MHz) as compared to the bands 5 925-6 425 MHz and 3 700-4 200 MHz.

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* Minimum distance is the distance for ESV stations beyond which these stations are assumed not to have the potential to cause unacceptable interference to stations of fixed service.

1